Physical and Chemical Characterization of Salmonid Feed Pellets

S.A. Petersen, T.F. Sutherland, and D. Higgs

Fisheries and Oceans Canada
Science Branch – Pacific Region
Marine Ecosystem and Aquaculture Division
DFO-UBC Centre for Aquaculture and Environmental Research
4160 Marine Drive
West Vancouver, B.C.
V7V 1N6

2005

Canadian Data Report of Fisheries and Aquatic Sciences 1159

Fisheries and Oceans / Pêches et Océans

Canada

Canadian Data Report of
Fisheries and Aquatic Sciences

Data reports provide a medium for filing and archiving data compilations where little or no analysis is included. Such compilations commonly will have been prepared in support of other journal publications or reports. The subject matter of data reports reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Data reports are not intended for general distribution and the contents must not be referred to in other publications without prior written authorization from the issuing establishment. The correct citation appears above the abstract of each report. Data reports are abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1 - 25 in this series were issued as Fisheries and Marine Service Data Records. Numbers 26 - 160 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Data Reports. The current series name was introduced with the publication of report number 161.

Data reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport statistique canadien des
sciences halieutiques et aquatiques

Les rapports statistiques servent à classer et à archiver les compilations de données pour lesquelles il y a peu ou point d'analyse. Ces compilations auront d'ordinaire été préparées à l'appui d'autres publications ou rapports. Les sujets des rapports statistiques reflètent la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports statisiques ne sont pas destinés à une vaste distribution et leur contenu ne doit pas être mentionné dans une publication sans autorisation écrite préalable de l'établissement auteur. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports statisiques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 25 de cette série ont été publiés à titre de relevés statistiques, Services des pêches et de la mer. Les numéros 26 à 160 ont été publiés à titre de rapports statistiques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 161.

Les rapports statistiques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

105-04194/

Canadian Data Report of
Fisheries and Aquatic Sciences 1159

2005

PHYSICAL AND CHEMICAL CHARACTERIZATION OF SALMONID FEED PELLETS

by

S.A. Petersen, T.F. Sutherland, and D. Higgs

Fisheries and Oceans Canada
Science Branch – Pacific Region
Marine Ecosystem and Aquaculture Division
DFO-UBC Centre for Aquaculture and Environmental Research
4160 Marine Drive
West Vancouver, B.C.
V7V 1N6

© Her Majesty the Queen in Right of Canada, 2005.
Cat. No. Fs 97-13/1159E ISSN 0706-6465

Correct citation for this publication:

Petersen, S.A., Sutherland, T.F., and Higgs, D. 2005. Physical and chemical characterization of salmonid feed pellets. Can. Data. Rep. Fish. Aquat. Sci. 1159: iv + 12 p.

LIST OF TABLES

Table		
1	Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 3.5 mm salmonid feed pellet type.....	3
2	Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 5.0 mm salmonid feed pellet type.....	3
3	Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 6.5 mm salmonid feed pellet type.....	4
4	Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 8.5 mm salmonid feed pellet type.....	4
5	Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 11.0 mm salmonid feed pellet type.....	5
6	Physical characteristics and percentages of moisture and ash (air-dry basis) for the Farm A salmonid feed pellet type.....	5
7	Replicate and mean values for semi-trace metal concentrations in the Orion 3.5 mm salmonid feed pellet type.....	6
8	Replicate and mean values for semi-trace metal concentrations in the Orion 5.0 mm salmonid feed pellet type.....	7
9	Replicate and mean values for semi-trace metal concentrations in the Orion 6.5 mm salmonid feed pellet type.....	8
10	Replicate and mean values for semi-trace metal concentrations in the Orion 8.5 mm salmonid feed pellet type.....	9
11	Replicate and mean values for semi-trace metal concentrations in the Orion 11.0 mm salmonid feed pellet type.....	10
12	Replicate and mean values for semi-trace metal concentrations in the Farm A salmonid feed pellet type.....	11
13	Carbon, nitrogen and stable isotope estimates (air-dry basis) of six salmonid feed pellet types.....	12

ABSTRACT

Petersen, S.A., Sutherland, T.F., and Higgs, D. 2005. Physical and chemical characterization of salmonid feed pellets. Can. Data Rep. Fish Aquat. Sci. 1159: iv + 12 p.

The physical and chemical properties of a suite of salmonid feed pellets of varying sizes (Orion 3.5 mm, Orion 5.0 mm, Orion 6.5 mm, Orion 8.0 mm, and Orion 11.0 mm) manufactured by Skretting Canada, Vancouver, B.C. are presented in this data report. Pellet dimensions were measured along with estimates of moisture and inorganic contents. The chemical analyses of feed pellets included a semi-trace metal scan as well as carbon and nitrogen stable isotope determinations. The data arising from this report will support models designed to determine the fate of salmonid feed pellets in the marine environment.

RESUMÉ

Petersen, S.A., Sutherland, T.F., and Higgs, D. 2005. Physical and chemical characterization of salmonid feed pellets. Can. Data Rep. Fish Aquat. Sci. 1159: iv + 12 p.

Sont présentées dans ce Rapport statistique canadien les données physiques et chimiques d'une gamme de granulés Orion pour salmonidés (3,5 mm, 5,0 mm, 6,5 mm, 8,0 mm et 11,0 mm), fabriqués par Skretting Canada, de Vancouver (C.-B.). La dimension des granulés a été mesurée, et des estimations faites de leurs teneurs en humidité et en éléments inorganiques. Les analyses chimiques comprenaient le dépistage des métaux lourds ainsi que des déterminations des teneurs en isotopes lourds de carbone et d'azote. Cette information servira à l'élaboration de modèles du devenir des granulés pour salmonidés dans le milieu marin.

INTRODUCTION

Although the salmon aquaculture industry has adopted feeding strategies to reduce the amount of feed loss through the netpen systems through the use of feed-detection systems including acoustic sensors (Juell et al. 1993) and subsurface video imagery (Ang and Petrell 1997), uneaten feed pellets may pass through the cage system and potentially accumulate on the underlying benthic environment. Knowledge of waste pellet characteristics is required in order to predict the fate of feed pellet waste in the environment through the use of hydrodynamic models (Panchang et al. 1997; Dudley et al. 2000; Cromey et al. 2002). The chemical composition of pellets may help to identify a tracer which can be used to track waste material in the benthic environment and validate predicted dispersal fields.

MATERIALS AND METHODS

PHYSICAL CHARACTERISTICS

The fish feed pellets obtained from Moore-Clarke Co., Vancouver, B.C. (presently Skretting Canada, Vancouver, B.C.) consisted of a winter diet ranging in size (Orion 3.5 mm, Orion 5.0 mm, Orion 6.5 mm, Orion 8.5 mm, and Orion 11.0 mm). In addition, a sample of unknown feed pellets was obtained from a salmon farm located in the Broughton Archipelago, British Columbia. The length and width dimensions of 10 replicates of each pellet type were measured using metric dial calipers. Moisture content was determined by the differential weight between air-dry and oven-dry pellets standardized by the air-dry weights according to AOAC Official Method 934.01 (Horwitz 2000). Moisture content was determined for a set of 10 replicates. Pellets were dried in a VWR 1370GM gravity oven. Inorganic content was determined by the differential weight between oven-dry and ashed pellets standardized by the oven-dry weights according to AOAC Official Method 942.05 (Horwitz 2000). Ashed weights were obtained for a set of 10 replicates for each pellet type. Pellets were ashed in a Thermodyne 1400 furnace. The mean and standard deviation of each measurement was calculated for all sets of replicates.

CHEMICAL CHARACTERISTICS

The concentrations of major (Al, Ca, Fe, Mg, P, K, Si, Na and S) and minor (Sb, As, Ba, Be, Bi, Cd, Cr, Co, Cu, Pb, Li, Mn, Mo, Ni, Se, Ag, Sr, Th, Sn, Ti, U, V, Zn and Zr) elements were determined by inductively coupled plasma atomic emission spectroscopy. Digestion of samples was carried out using a Strong Acid Leachable Metals (SALM) technique. A sample size of 1g was digested for 2 hours at 90°C in a 5mL mixture of 3 parts nitric acid and 1 part hydrochloric acid in accordance with US EPA Metals and Trace Elements by Ultrasonic Nebulization Method ICP-AES 200.15 (EPA 1994). Trace metal concentrations were determined using a Leeman Labs PF3000 UV ICP-AES coupled with a Cetac ultrasonic nebulizer with detection levels set at a semi-trace metal level. Total particulate carbon, total particulate nitrogen, $\delta^{13}C$ and $\delta^{15}N$ were determined using a Carlo-Erba CHN analyzer (precision ± 1.2%) on air-dry pellets.

A VG prism mass spectrometer (precision ± 0.2%) was coupled to the same type of analyzer for the carbon and nitrogen isotope analysis. These analyses were conducted for 3 replicates of each salmonid feed pellet type.

ACKNOWLEDGEMENTS

Trace metal analysis was conducted at Norwest Laboratories, Surrey, B.C. Carbon and nitrogen isotope analyses were conducted at the Department of Earth and Ocean Sciences at the University of British Columbia. The salmonid feed pellets used in the experiment were donated by Moore-Clarke Co. (presently Skretting Canada, Vancouver, B.C).

REFERENCES

Ang, K.P., and Petrell, R.J. 1997. Control of feed dispensation in seacages using underwater video monitoring: effects on growth and food conversion. Aquacult. Eng. 16: 45 - 62.

Cromey, C.J., Thomas,T.D., and Black, K.D. 2002. DEPOMOD – modeling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211 – 239.

Dudley, R.W., Panchang, V.G.,and Newell, C.R. 2000. Application of a comprehensive modeling strategy for the management of net-pen aquaculture waste transport. Aquaculture 187: 319 – 349.

Horwitz, W. (Editor). 2000. Official methods of analysis of AOAC International, 17th Edition, 1 (4): 1- 15.

Juell, J.E., Furevik, D.M., and Bjordal, A. 1993. Demand feeding in salmon farming by hydroacoustic food detection. Aquacult. Eng. 12: 155 - 167.

Panchang, V., Cheng, G., and Newell, C. 1997. Modeling hydrodynamics and aquaculture waste transport in coastal Maine. Estuaries 20 (1): 14 - 41.

US EPA. 1994. US EPA Metals and trace elements by ultrasonic nebulization method ICP-AES 200.15.

Table 1. Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 3.5 mm salmonid feed pellet type (S.D. = Standard Deviation).

Replicate	Length (mm)	Width (mm)	Moisture content (%)	Inorganic content (% ash)
1	3.9	3.6	6.82	9.82
2	4.0	3.8	7.14	9.62
3	4.4	3.5	7.10	9.55
4	5.2	3.7	7.07	11.91
5	3.8	3.8	6.62	10.07
6	4.3	3.5	7.24	8.73
7	4.0	3.6	6.90	9.35
8	5.1	3.4	6.94	9.93
9	4.0	3.7	7.23	9.36
10	5.0	3.6	7.27	10.16
Mean	4.4	3.6	7.03	9.85
(S.D.)	(0.5)	(0.1)	(0.20)	(0.79)

Table 2. Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 5.0 mm salmonid feed pellet type (S.D. = Standard Deviation).

Replicate	Length (mm)	Width (mm)	Moisture content (%)	Inorganic content (% ash)
1	6.7	5.6	5.38	8.29
2	6.7	5.2	5.04	7.96
3	6.4	5.4	5.21	8.15
4	7.4	5.4	5.65	8.39
5	7.9	5.5	5.44	8.17
6	8.7	5.5	4.97	8.19
7	7.8	5.7	5.13	8.11
8	6.5	5.4	5.14	8.19
9	5.6	5.4	4.90	6.20
10	7.4	5.7	4.89	7.95
Mean	7.1	5.5	5.17	7.96
(S.D.)	(0.8)	(0.2)	(0.24)	(0.60)

Table 3. Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 6.5 mm salmonid feed pellet type (S.D. = Standard Deviation).

Replicate	Length (mm)	Width (mm)	Moisture content (%)	Inorganic content (% ash)
1	9.2	6.6	5.63	7.74
2	10.0	6.0	5.65	8.06
3	9.1	7.2	6.02	8.35
4	9.2	6.5	6.59	8.40
5	8.9	6.5	6.11	8.73
6	9.2	6.0	5.64	8.16
7	8.7	6.6	6.11	8.14
8	10.0	6.5	5.89	8.05
9	8.3	6.7	6.53	8.50
10	9.2	7.1	5.65	8.12
Mean	9.2	6.6	5.98	8.23
(S.D.)	(0.5)	(0.4)	(0.34)	(0.26)

Table 4. Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 8.5 mm salmonid feed pellet type (S.D. = Standard Deviation).

Replicate	Length (mm)	Width (mm)	Moisture content (%)	Inorganic content (% ash)
1	13.1	8.3	5.90	6.79
2	11.3	8.5	6.17	7.52
3	13.4	8.6	6.01	7.28
4	11.7	8.6	5.89	7.28
5	11.6	8.8	6.83	8.58
6	12.4	8.0	5.89	7.14
7	12.6	9.2	5.89	7.22
8	11.5	8.3	5.99	7.42
9	12.4	8.1	5.99	7.28
10	11.4	8.9	6.13	7.67
Mean	12.1	8.5	6.07	7.42
(S.D.)	(0.7)	(0.4)	(0.27)	(0.45)

Table 5. Physical characteristics and percentages of moisture and ash (air-dry basis) for the Orion 11.0 mm salmonid feed pellet type (S.D. = Standard Deviation).

Replicate	Length (mm)	Width (mm)	Moisture content (%)	Inorganic content (% ash)
1	15.1	10.8	6.09	7.29
2	14.0	10.4	6.72	7.92
3	13.9	11.5	6.58	7.77
4	14.2	10.5	6.56	7.67
5	13.2	11.1	6.45	7.72
6	13.4	11.4	6.25	7.54
7	12.9	10.9	6.53	7.91
8	13.9	10.9	6.43	7.94
9	15.8	11.0	6.36	7.44
10	12.9	11.0	6.29	7.61
Mean	13.9	11.0	6.43	7.68
(S.D.)	(0.9)	(0.3)	(0.18)	(0.20)

Table 6. Physical characteristics and percentages of moisture and ash (air-dry basis) for the Farm A salmonid feed pellet type (S.D. = Standard Deviation).

Replicate	Length (mm)	Width (mm)	Moisture content (%)	Inorganic content (% ash)
1	12.00	10.33	4.62	8.49
2	13.50	11.00	4.59	8.34
3	12.55	10.78	4.77	8.38
4	12.10	10.88	4.61	8.36
5	12.85	10.78	4.68	8.38
6	13.95	10.80	4.46	8.45
7	12.30	10.70	4.69	8.21
8	11.80	10.45	4.52	8.44
9	15.00	10.78	4.75	8.36
10	11.75	10.83	4.67	8.38
Mean	12.80	10.70	4.64	8.38
(S.D.)	(1.0)	(0.2)	(0.09)	(0.07)

Table 7. Replicate and mean values for semi-trace metal concentrations in the Orion 3.5 mm salmonid feed pellet.

Orion 3.5 mm Pellet					
Element	Pellet 1 ($\mu g\ g^{-1}$)	Pellet 2 ($\mu g\ g^{-1}$)	Pellet 3 ($\mu g\ g^{-1}$)	Mean	Standard Deviation
Aluminum	18	17	24	20	3
Antimony	0	0	0	0	0
Arsenic	0	0	0	0	0
Barium	2.45	2.41	2.69	2.52	0.12
Beryllium	0.00	0.00	0.00	0.00	0.00
Bismuth	0	0	0	0	0
Cadmium	0.44	0.47	0.53	0.48	0.04
Calcium	22100	22100	22100	22100	0
Chromium	0.7	0.7	0.7	0.7	0.0
Cobalt	0.0	0.0	0.0	0.0	0.0
Copper	7.3	7.3	7.9	7.5	0.3
Iron	152.0	127.0	157.0	145.3	13.1
Lead	0.0	0.0	0.0	0.0	0.0
Lithium	0.0	0.5	0.0	0.2	0.2
Magnesium	1550	1580	1660	1597	46
Manganese	19.40	19.80	21.10	20.10	0.73
Molybdenum	0	0	0	0	0
Nickel	33.0	6.0	0.2	13.1	14.3
Phosphorus	15900	16000	16100	16000	82
Potassium	6990	7040	7430	7153	197
Selenium	0	0	0	0	0
Silicon	316	491	543	450	97
Silver	0.0	0.0	0.0	0.0	0.0
Sodium	7250	7210	7510	7323	133
Strontium	34.2	33.8	35.3	34.4	0.6
Sulfur	6500	6800	6700	6667	125
Thorium	0.0	0.0	0.0	0.0	0.0
Tin	0.0	0.0	0.0	0.0	0.0
Titanium	0.5	0.4	0.8	0.6	0.2
Uranium	0	0	0	0.0	0.0
Vanadium	0.0	0.0	0.0	0.0	0.0
Zinc	91.50	95.10	97.30	94.63	2.39
Zirconium	0.0	0.0	0.0	0.0	0.0

Table 8. Replicate and mean values for semi-trace metal concentrations in the Orion 5.0 mm salmonid feed pellet.

Orion 5.0 mm Pellet					
Element	Pellet 1 ($\mu g\ g^{-1}$)	Pellet 2 ($\mu g\ g^{-1}$)	Pellet 3 ($\mu g\ g^{-1}$)	Mean	Standard Deviation
Aluminum	30	27	29	29	1
Antimony	0	0	0	0	0
Arsenic	0	0	0	0	0
Barium	3.57	3.20	3.42	3.40	0.15
Beryllium	0.00	0.00	0.00	0.00	0.00
Bismuth	0	0	0	0	0
Cadmium	0.32	0.27	0.32	0.30	0.02
Calcium	18000	10600	17700	15433	3420
Chromium	0.9	0.5	0.5	0.6	0.2
Cobalt	0.0	0.0	0.0	0.0	0.0
Copper	9.4	8.6	8.9	9.0	0.3
Iron	156.0	147.0	157.0	153.3	4.5
Lead	0.0	0.0	0.0	0.0	0.0
Lithium	0.0	0.0	0.0	0.0	0.0
Magnesium	1330	1280	1250	1287	33
Manganese	19.40	16.70	19.30	18.47	1.25
Molybdenum	0	0	0	0	0
Nickel	0.6	0.3	0.4	0.4	0.1
Phosphorus	13000	13400	12900	13100	216
Potassium	5930	5630	5590	5717	152
Selenium	0	0	0	0	0
Silicon	533	593	574	567	25
Silver	0.0	0.0	0.0	0.0	0.0
Sodium	5790	5460	5560	5603	138
Strontium	26.5	25.4	25.9	25.9	0.5
Sulfur	6200	6200	6000	6133	94
Thorium	0.0	0.0	0.0	0.0	0.0
Tin	0.0	0.0	0.0	0.0	0.0
Titanium	3.4	1.1	1.1	1.9	1.1
Uranium	0	0	0	0	0
Vanadium	0.0	0.0	0.0	0.0	0.0
Zinc	82.40	75.80	80.10	79.43	2.74
Zirconium	0.0	0.0	0.0	0.0	0.0

Table 9. Replicate and mean values for semi-trace metal concentrations in the Orion 6.5 mm salmonid feed pellet.

Element	Orion 6.5 mm Pellet				
	Pellet 1 ($\mu g\ g^{-1}$)	Pellet 2 ($\mu g\ g^{-1}$)	Pellet 3 ($\mu g\ g^{-1}$)	Mean	Standard Deviation
Aluminum	39	54	50	48	6
Antimony	0	0	0	0	0
Arsenic	0	0	0	0	0
Barium	2.77	2.95	3.18	2.97	0.17
Beryllium	0.00	0.00	0.00	0.00	0.00
Bismuth	0	0	0	0	0
Cadmium	0.31	0.41	0.46	0.39	0.06
Calcium	18000	17100	18300	17800	510
Chromium	0.6	0.7	0.6	0.6	0.1
Cobalt	0.0	0.1	0.0	0.0	0.1
Copper	9.5	9.2	9.0	9.2	0.2
Iron	233.0	203.0	174.0	203.3	24.1
Lead	0.0	0.0	0.0	0.0	0.0
Lithium	0.0	0.0	0.0	0.0	0.0
Magnesium	1200	1370	1520	1363	131
Manganese	22.60	24.50	26.00	24.37	1.39
Molybdenum	0	0	0	0	0
Nickel	0.4	0.4	0.3	0.4	0.1
Phosphorus	13000	12600	13700	13100	455
Potassium	5430	6060	6640	6043	494
Selenium	0	0	0	0	0
Silicon	661	691	605	652	36
Silver	0.0	0.0	0.0	0.0	0.0
Sodium	4760	5330	5880	5323	457
Strontium	17.8	21.0	23.9	20.9	2.5
Sulfur	5900	5700	6100	5900	163
Thorium	0.0	0.0	0.0	0.0	0.0
Tin	0.0	0.0	0.0	0.0	0.0
Titanium	1.7	2.1	2.1	2.0	0.2
Uranium	0	0	0	0	0
Vanadium	0.0	0.0	0.0	0.0	0.0
Zinc	81.10	85.30	89.50	85.30	3.43
Zirconium	0.0	0.0	0.0	0.0	0.0

Table 10. Replicate and mean values for semi-trace metal concentrations in the Orion 8.5 mm salmonid feed pellet.

Element	Orion 8.5 mm Pellet				
	Pellet 1 ($\mu g\ g^{-1}$)	Pellet 2 ($\mu g\ g^{-1}$)	Pellet 3 ($\mu g\ g^{-1}$)	Mean	Standard Deviation
Aluminum	36	35	31	34	2
Antimony	0	0	0	0	0
Arsenic	0	0	0	0	0
Barium	2.42	2.40	2.30	2.37	0.05
Beryllium	0.00	0.00	0.00	0.00	0.00
Bismuth	0	0	0	0	0
Cadmium	0.41	0.39	0.38	0.39	0.01
Calcium	15000	13800	15000	14600	566
Chromium	0.5	0.5	0.5	0.5	0.0
Cobalt	0.2	0.1	0.0	0.1	0.1
Copper	7.4	7.2	8.7	7.8	0.7
Iron	203.0	216.0	202.0	207.0	6.4
Lead	0.0	0.0	0.0	0.0	0.0
Lithium	0.0	0.0	0.0	0.0	0.0
Magnesium	1340	1180	1390	1303	90
Manganese	39.70	20.20	20.00	27	9
Molybdenum	0	0	0	0	0
Nickel	0.4	0.3	0.3	0.3	0.1
Phosphorus	11600	10600	11600	11267	471
Potassium	5340	5140	5560	5347	172
Selenium	0	0	0	0	0
Silicon	701	727	653	694	31
Silver	0.0	0.0	0.0	0.0	0.0
Sodium	5020	4510	5210	4913	296
Strontium	20.3	17.8	21.1	19.7	1.4
Sulfur	5600	4770	5800	5390	446
Thorium	0.0	0.0	0.0	0.0	0.0
Tin	0.0	0.0	0.0	0.0	0.0
Titanium	1.3	2.0	1.2	1.5	0.4
Uranium	0	0	0	0	0
Vanadium	0.0	0.0	0.0	0.0	0.0
Zinc	77.90	74.40	82.20	78.17	3.19
Zirconium	0.0	0.0	0.0	0.0	0.0

Table 11. Replicate and mean values for semi-trace metal concentrations in the Orion 11.0 mm salmonid feed pellet.

Element	Orion 11.0 mm Pellet Type				
	Pellet 1 ($\mu g\ g^{-1}$)	Pellet 2 ($\mu g\ g^{-1}$)	Pellet 3 ($\mu g\ g^{-1}$)	Mean	Standard Deviation
Aluminum	45	59	47	50	6
Antimony	0	0	0	0	0
Arsenic	0	0	0	0	0
Barium	2.71	2.98	2.83	2.84	0.11
Beryllium	0.00	0.00	0.00	0.00	0.00
Bismuth	0	0	0	0	0
Cadmium	0.37	0.31	0.41	0.36	0.04
Calcium	14700	16100	16100	15633	660
Chromium	0.8	1.1	1.1	1.0	0.1
Cobalt	0.0	0.2	0.0	0.1	0.1
Copper	7.1	8.9	7.5	7.8	0.8
Iron	182.0	156.0	150.0	162.7	13.9
Lead	0.0	0.0	0.0	0.0	0.0
Lithium	0.0	0.0	0.0	0.0	0.0
Magnesium	1480	1590	1580	1550	50
Manganese	25.40	38.00	27.80	30.40	5.46
Molybdenum	0	0	0	0	0
Nickel	0.3	0.3	0.4	0.3	0.1
Phosphorus	11300	12400	12100	11933	464
Potassium	5710	6070	5950	5910	150
Selenium	0	0	0	0	0
Silicon	713	726	847	762	60
Silver	0.0	0.0	0.0	0.0	0.0
Sodium	4920	5400	5200	5173	197
Strontium	20.8	21.0	22.3	21.4	0.7
Sulfur	5200	5700	5600	5500	216
Thorium	0.0	0.0	0.0	0.0	0.0
Tin	0.0	0.0	0.0	0.0	0.0
Titanium	2.8	2.6	1.4	2.3	0.6
Uranium	0	0	0	0	0
Vanadium	0.0	0.0	0.0	0.0	0.0
Zinc	109.00	177.00	126.00	137.33	28.89
Zirconium	0.0	0.0	0.0	0.0	0.0

Table 12. Replicate and mean values for semi-trace metal concentrations in the Farm A salmonid feed pellet.

Element	Farm A Pellet				
	Pellet 1 ($\mu g\ g^{-1}$)	Pellet 2 ($\mu g\ g^{-1}$)	Pellet 3 ($\mu g\ g^{-1}$)	Mean	Standard Deviation
Aluminum	42	34	33	36	4
Antimony	0	0	0	0	0
Arsenic	0	0	0	0	0
Barium	3.58	3.41	3.57	3.52	0.08
Beryllium	0.00	0.00	0.00	0.00	0.00
Bismuth	0	0	0	0	0
Cadmium	0.40	0.39	0.40	0.40	0.00
Calcium	16700	17100	16100	16633	411
Chromium	1.3	1.2	1.4	1.3	0.1
Cobalt	2.8	2.7	2.7	2.7	0.1
Copper	10.5	10.0	10.7	10.4	0.3
Iron	272.0	260.0	243.0	258.3	11.9
Lead	0.6	0.0	0.0	0.2	0.3
Lithium	0.0	0.0	0.0	0.0	0.0
Magnesium	1950	1880	1840	1890	45
Manganese	17.90	17.90	21.10	18.97	1.51
Molybdenum	0	0	0	0	0
Nickel	0.5	0.5	0.5	0.5	0.0
Phosphorus	12800	13000	12400	12733	249
Potassium	7530	7230	7250	7337	137
Selenium	2	0	0	1	1
Silicon	906	467	713	695.33	179.66
Silver	0.0	0.0	0.0	0.0	0.0
Sodium	6800	6520	6550	6623	126
Strontium	30.2	29.7	30.1	30.0	0.2
Sulfur	5300	5010	5020	5110	134
Thorium	0.0	0.0	0.0	0.0	0.0
Tin	0.0	0.0	0.0	0.0	0.0
Titanium	2.2	2.2	2.3	2.2	0.1
Uranium	0	0	0	0	0
Vanadium	0.0	0.0	0.0	0.0	0.0
Zinc	128.00	113.00	112.00	117.67	7.32
Zirconium	0.0	0.0	0.0	0.0	0.0

Table 13. Carbon, nitrogen and isotope values measured (air-dry basis) in six salmonid feed pellet types (S.D. = Standard Deviation).

Pellet Type	Replicate	Total Carbon Content (%)	Mean % Total C (S.D.)	$\delta^{13}C$	Mean $\delta^{13}C$ (S.D.)	Total Nitrogen Content (%)	Mean % Total N (S.D.)	$\delta^{15}N$	Mean $\delta^{15}N$ (S.D.)	Carbon Nitrogen Ratio	Mean CN Ratio (S.D.)
3.5	1	49.86		-20.53		8.65		12.3		5.76	
	2	49.24	49.29	-20.98	-20.88	8.44	8.52	13.0	12.5	5.83	5.78
	3	48.78	(0.44)	-21.15	(0.26)	8.48	(0.09)	12.1	(0.4)	5.75	(0.03)
5.0	1	52.19		-21.33		7.79		9.6		6.70	
	2	51.89	51.42	-21.49	-21.33	7.91	7.88	10.4	10.0	6.56	6.53
	3	50.19	(0.88)	-21.16	(0.13)	7.94	(0.06)	10.2	(0.3)	6.32	(0.15)
6.5	1	52.79		-22.46		7.32		9.5		7.21	
	2	48.99	50.25	-20.94	-21.85	7.83	7.36	11.1	9.9	6.26	6.85
	3	48.98	(1.79)	-22.15	(0.65)	6.93	(0.37)	9.2	(0.9)	7.07	(0.42)
8.5	1	55.80		-21.92		6.58		11.3		8.48	
	2	53.83	54.06	-22.05	-21.98	7.06	6.78	10.9	11.0	7.63	7.98
	3	52.54	(1.34)	-21.96	(0.06)	6.71	(0.20)	10.9	(0.2)	7.84	(0.36)
11.0	1	51.59		-22.00		6.81		9.6		7.58	
	2	51.59	51.31	-22.17	-22.02	6.29	6.51	9.7	10.2	8.20	7.89
	3	51.13	(0.24)	-21.90	(0.11)	6.49	(0.19)	11.5	(0.9)	7.88	(0.22)
Farm A	1	51.22		-21.94		7.02		10.6		7.30	
	2	51.90	51.41	-21.79	-21.91	6.38	6.57	10.3	10.4	8.13	7.85
	3	51.12	(0.35)	-21.99	(0.09)	6.30	(0.32)	10.5	(0.1)	8.12	(0.39)